



Albarrak, L. Y. S., Metatla, O., & Roudaut, A. (2020). Exploring the Design of History-Enriched Floor Interfaces for Asynchronous Navigation Support. In *DIS '20: Proceedings of the 2020 ACM Designing Interactive Systems Conference* (pp. 1391–1403). Association for Computing Machinery (ACM).
<https://doi.org/10.1145/3357236.3395496>

Peer reviewed version

Link to published version (if available):
[10.1145/3357236.3395496](https://doi.org/10.1145/3357236.3395496)

[Link to publication record in Explore Bristol Research](#)
PDF-document

This is the author accepted manuscript (AAM). The final published version (version of record) is available online via ACM at <https://dl.acm.org/doi/10.1145/3357236.3395496>. Please refer to any applicable terms of use of the publisher.

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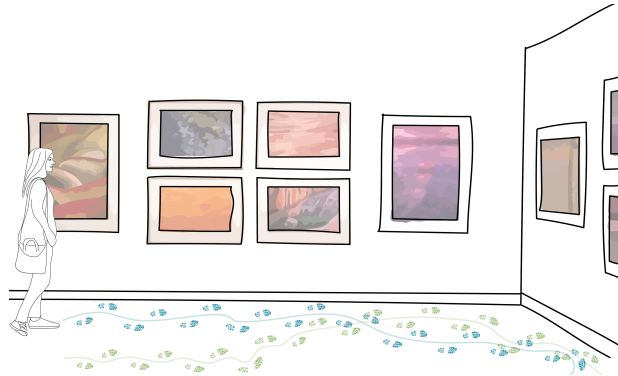
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Exploring the Design of History-Enriched Floor Interfaces for Asynchronous Navigation Support

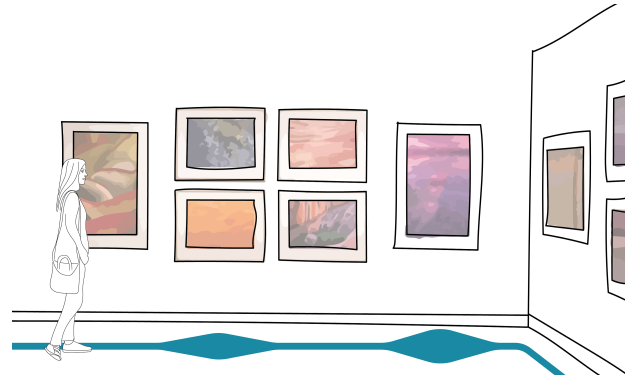
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(a) Footprints to represent individual experiences. Colour-codes can be used to represent different users, interests or space familiarity.



(b) Aggregated representation to represent collective experiences. Line thickness can be used to convey additional layer of information such as likes.

Figure 1: Illustrations of design ideas suggested by our participants. They both use digital navigation traces to support exploration and navigation in public spaces: one is using concrete representation such as footsteps while the other one use a more abstract representation to show where most people have been.

ABSTRACT

Environmental cues influence our spatial behaviour when we explore unfamiliar spaces. Research particularly shows that the presence/actions of other people affects our navigation decisions. Here we examine how such social information can be integrated digitally into the environment to support navigation in indoor public spaces. We carried out a study ($n=12$) to explore how to represent traces of navigation behaviour. We compared 6 floor visualisations and examined how they affect participants' navigational choices. Results suggest that direct representations such as footprints are most informative. To investigate further how such visualisation could work in practice, we implemented an interactive floor system and used it as probe during one-to-one design sessions ($n=26$). We particularly focused on four design challenges: the overall visual representation, representation of multiple people, designing more prominent visualisations and the incorporation of

non-identifying information. Our results provide insights for designers looking to develop history-enriched floor interfaces.

Author Keywords

Social Navigation; Floor Displays; Public spaces; Social Annotations; Design

CCS Concepts

•Human-centered computing → HCI design and evaluation methods; Human computer interaction (HCI);

INTRODUCTION

When faced with the task of exploring and navigating unfamiliar spaces, people use physical characteristics of the environment (e.g. architecture) but they also rely heavily on social cues. Specifically, research have shown that the presence and/or actions of other people have a noticeable influence on our navigational decisions [12]. Such actions can even be asynchronous, i.e. performed in the past. For example it is the case when physical traces left by other people in a park encourages us to take that path and discover interesting areas.

This concept of asynchronous social navigation has inspired researchers to propose systems that help in navigating information spaces by collecting digital traces of people's web activity [16]. Later, location-based social networks have also leveraged this notion to support navigation and exploration of

outdoor places. Such social navigation systems were shown to support collaboration among users and to provide better exploration and navigation experiences [16, 15]. Using asynchronous social navigation can also benefit indoor spaces such as museums. For example it has been shown that complex problem-solving tasks such as navigation become easier and visitors' experiences become richer [7, 11, 47].

However, systems that support social navigation in indoor spaces use mobile devices as platform to display social information, which is not ideal. It particularly forces the users to divide their attention between the device and their primary task, e.g. looking at pieces within a museum or searching for a particular location. We believe that a better integration of technology and environment can occur. Our work is particularly inspired by the increasing use of interactive floor as an assistive display [51], a behaviour change tool [39] or as an ambient display that promotes situational awareness [31]. In this paper, we explore a new usage of interactive floor interfaces and investigate how they can be designed and used to visualise, present and integrate social navigational traces into public spaces, and whether and how they would affect people's navigational decisions when such social information accumulate.

We call this new usage of interactive floors *history-enriched floor interfaces*, i.e. floor interfaces that show navigational traces of previous users. Our approach to investigate their design consisted of two steps:

1. Our first study explored six visualisations of navigation traces to understand how social information affects people's decisions, and how they are interpreted. Our findings showed that usage and navigational traces is not the only factor that affects decisions, other factors such as feelings, preferences and different environmental features also play a crucial role. Our findings showed that the heatmap visualisation was rated the best, although it was also the most misunderstood. As a result footprints visualisation provides a clear and direct representation of navigation traces. We also identified key challenges in the design of *history-enriched floor interfaces*: the visual representation and its features, representation of multiple people, designing more prominent visualisations and the incorporation of additional non-identifying information.
2. To further investigate how such floor interfaces could work in practice and explore the challenges highlighted in the first study, we engaged potential users directly in the design of potential solutions to these challenges. We focused on footprints visualisation based on findings from our first study and implemented a top projection floor display that tracks and displays the user's footprints. We used this as a technological probe during individual design sessions with 26 participants. We particularly examined the design challenges we identified in the evaluation study to drive the design sessions.

We report on the design process and the outcomes of the evaluation study and the design sessions. To summarise, the contributions of this work are (1) a study demonstrating how

different floor visualisations that show traces of navigation behaviour affect navigational decisions and how they are interpreted; (2) a study identifying key design challenges of using history-enriched floor interfaces in public spaces; and (3) a set of design opportunities and novel insights into the design of history-enriched floor interfaces in four design challenges.

BACKGROUND

Our work relates to understanding spatial behaviour in public spaces; stigmergy and social navigation; social annotation systems and digital navigational guides in public spaces. We finish by presenting existing interactive floor systems.

Understanding Spatial Behaviour in Public Spaces

Studies have reported many factors that influence spatial behaviour, and in particular path choice behaviour, within the built environment. For instance, research have shown that personal factors such as personal preferences [17] and walking habits (e.g. turning right) [6] tend to influence the choices people make. In addition, environmental factors, have been shown to influence path choice behaviour. In particular, architectural aspects of the space such as the location of entrance and exit, length of the path and position and number of doors, can have this influence [38, 45, 22].

Other architectural features that have been found to influence path choice behaviour include the width and ceiling height of the path [54, 53, 52]. Salient and attention-grabbing objects offering qualities of beauty, curiosity, or educational value in an area have also been found to impact spatial behaviour in public spaces [38]. In addition, social characteristics such as the presence and the absence of people in the space affects spatial behaviours [13, 58]. Recently, Dalton *et al.* [12] discussed how the presence and/or activities of others (present or past) impacts spatial behaviours and particularly wayfinding. In their work, they argue that *social wayfinding* can be classified into two types: "*Strong*" and "*weak*" social wayfinding. Strong social wayfinding involves intentional communication between the sender and receiver whereas the communication is unintentional between them in the weak social wayfinding.

These two types have also been classified according to the time frame in which they take place into synchronous and asynchronous. The synchronous type occurs when the sender and receiver are co-present in time and space whereas the sender and receiver are not co-present in the asynchronous type [12]. For example, synchronous strong type occurs when individuals collaborate to make wayfinding decisions, while asynchronous weak type occurs when a person is guided by the physical traces that previous people have left [12].

Stigmergy and Social Navigation

By observing the collective behaviour of coordination and regulation in social animals and insects, the zoologist Grasse' discovered the phenomenon of indirect communication mediated by modifications of the environment among agents - *stigmergy* [20, 29]. This communication can occur via modification of the physical environment (e.g. trails in a park) or via a signalling mechanism (e.g. social insects use of pheromones to mark trails) [29]. In complex situations, humans also behave and cooperate in a similar manner in order to achieve common goals.

These findings have inspired researchers to apply the concept of stigmergy in different human domains such as artificial intelligence and robotics [10, 19]. One example is Amazon.com's use of collaborative filtering (CF) technique that allow humans to leave digital traces that can be tracked, analysed and aggregated [29]. CF allows users to leverage social knowledge to navigate and explore items of interest [16]. Dourish and Chalmers [16] describe this utilisation of users' activity patterns to navigate the information space as *social navigation*. Though employing this concept has focused on web applications, the development of mobile technology has extended its use to location-based social services. Such services allow users to navigate the real-world using digital social annotations and traces left by previous visitors [24]. In this work, we build on and extend this work by exploring how such digital navigation traces can be designed and integrated into the environments to support exploration and navigation of indoor spaces.

Social Annotation Systems in Public Spaces

Social/public annotation systems allow people to share content (e.g. comments, photos, recommendations) with others and build collective knowledge spaces when such content accumulates [35]. Though social annotations have been studied extensively in HCI (e.g. [27, 4, 23, 26]), few efforts have been made to enrich visitors' experiences in public spaces through such social annotations. Research has shown that using annotation systems in museums have improved experiences and supported active visitor participation [7, 11]. Also, Stevens *et al.* [47] demonstrated that recording visitors' annotations and descriptions of museum exhibits have helped in understanding the learning process and have supported connection between visitors. Cosley *et al.* [11] also showed that social annotations can support museum navigation.

However, all of these systems used additional handheld devices to annotate and display information, which could negatively affect the exploration experience and cause dissociation from the physical space [11]. Recently, this line of research has been extended within an extended abstract piece of work proposing to integrate social information directly into the environment to support navigation [1]. We build on this work and expand it further to closely examine design challenges of integrating social information in indoor spaces.

Digital Navigational Guides in Public Spaces

Different navigational guides have been used in public spaces to help visitors navigate unfamiliar spaces including digital signs, interactive maps, navigational assistants such as audio guides and mobile devices. Interactive maps displayed using public displays or mobile devices are the most commonly used guide since they facilitate the configurational understanding of spaces [33]. However, maps can sometimes be difficult to read and can lead to disorientation [32]. Navigational assistants provide navigational instructions that direct the navigator on what to do at each step but operating such devices while navigating can direct the attention of the navigator away from the surrounding environment [43, 55]. In order to address this issue, researchers have started to investigate hands-free navigation methods that provide tactile feedback using wearables [28],

belts [49, 48] and shoes [50, 42]. However, tactile-based navigation systems are less efficient compared to visual handheld navigation assistants [37].

Although researchers acknowledge the problems associated with navigational assistants [56, 2], few efforts have been made to support navigation in a way that does not negatively affect the navigator's experience. Moreover, traditional navigational guides used in public spaces lack support for social exploration and navigation. Despite their important role in supporting navigation, collaboration and communication between visitors [7, 11, 47], little work has been done to leverage such social information to support navigation in public spaces. In this work, we suggest that using floor interfaces that show spatially contextualised social information (i.e. traces of navigation behaviour) could address the aforementioned issues and provide navigation support in indoor spaces. As a first step, we explore the design of such floor interfaces and examine whether and how navigational traces impact navigational decisions.

Interactive Floor Systems

Much of the HCI research on floor displays has focused on supporting interactions with the display. These studies have investigated different implementation methods of interactive floors (i.e. sensor-based or vision-based), interaction techniques, user identification and ways to expand the display area [3, 34, 8, 21, 14]. So far, interactive floor displays have been used mainly in entertainment and multi-user collaborative applications (e.g. [25, 21]). There has been less research, however, on how to utilise them in other application domains. Recently, researchers have proposed to use interactive floors as an assistive display [51], behaviour change tool [39] and as a tool to promote situational awareness [31]. In addition, efforts have been made to support navigation using floor displays (e.g. [36, 40, 57]). While these efforts uncover many of the potentials of floor displays, using floor displays that show social information as a navigation guide in indoor spaces remains largely unexplored.

STUDY 1: VISUALISATION IDEATION AND EVALUATION

To start exploring how to visualise, present and integrate asynchronous navigational traces digitally into public spaces and particularly on interactive floors, we started by exploring different visualisations of traces of navigation behaviour. We particularly examined whether and how the *accumulation* of navigational traces affects navigational decisions, and explored how people interpret the visualisations. We obtained Ethics approval from the university's ethics committee before conducting the study.

Task

To explore the effect of different social traces visualisations on users, we created a building navigation task where participants were shown two corridors with each visualisation representing a high usage level (many traces) or a low usage level (few traces). There were six different visualisations: time difference, heatmap, dots, footsteps, line type and lines as shown in Figure 2. These visualisations were generated during a 15 minutes brainstorming session with eight participants (different from the study reported here). They were asked to generate

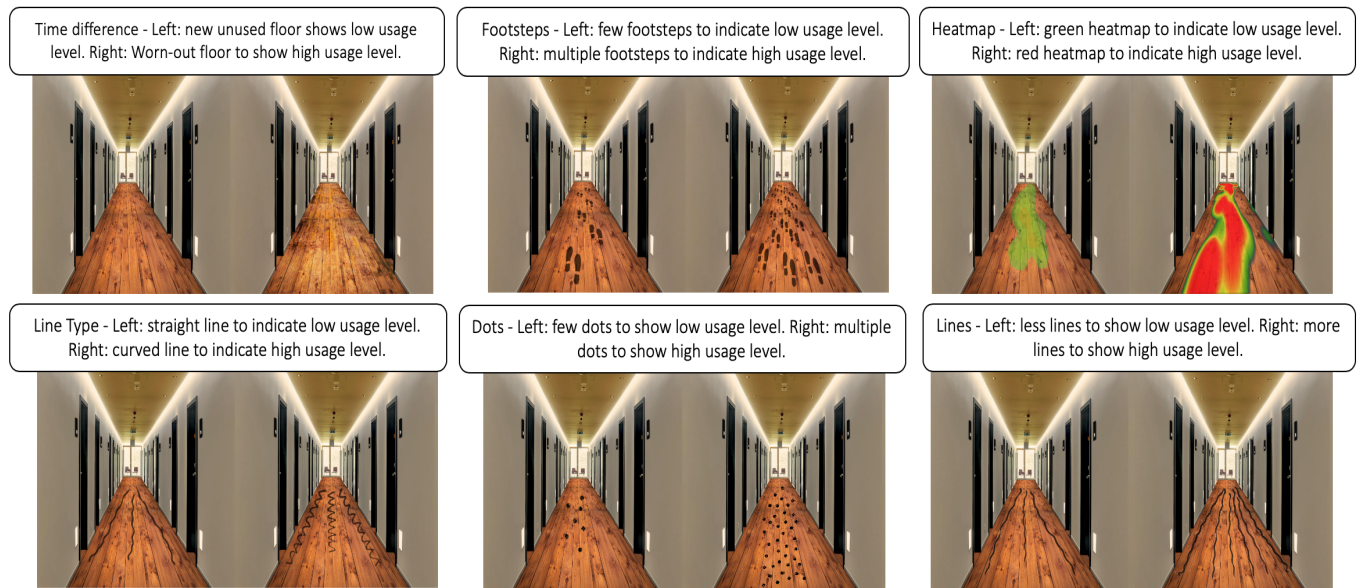


Figure 2: Selected visualisations to represent traces of navigation behaviour of other people include time difference, footsteps, heatmap, line type, dots and lines.



Figure 3: Experimental setup in our first study.

sketches that represent "traces of navigation behaviour". The building navigation task was projected on a wall in front of the user in order to mimic navigation in real setup and scale. The participants had to choose one and explain their rationale.

Setup

The study took place in a lab space at the author's institution. Participants were facing a large projected display. We used a short-throw projector (BenQ MW864UST, running at 1920x1080p resolution). The images of the two corridors were projected on a wall in front of the participants so that the image were 1.5 meters high. We chose this setup to mimic a real

navigation situation and to approach real corridor scale seen from the participants point of view.

Procedure

Upon arrival, participants were given an overview of the study and were then asked to complete the consent form and demographics questionnaire. We conducted structured interviews with participants to evaluate the selected visualisations (Figure 2). We asked participants to answer questions given by the researcher verbally while facing the visualisations (Figure 3). In the first part of the interview, we presented an indoor navigation scenario and asked participants to select their path choices and justify their decisions in six different situations. Next, we asked participants to provide their own interpretation of the meaning of each visualisation. Finally, participants were told that the shown visualisations were selected to represent navigation traces of previous people, and they were asked to rank the top three that they thought presented this information in the most meaningful way. The researcher took written notes of the participants' answers. The interview took approximately 15 minutes to complete.

Data Collection and Analysis

The researcher took notes and recorded the participant's answers on pre-formatted answer sheets. We analysed the frequency of navigation choices for each of the selected visualisation. We used a thematic analysis with an inductive coding approach to analyse participants' justification of their path choices. One author read and openly coded the interview. Following this, we conducted peer validation throughout the coding process with an additional researcher to review and clarify codes and emerging themes. We used the qualitative data analysis software, NVivo to thematically analyse our data. Visualisation ranking was analysed by calculating frequency

of responses and applying different weights for each of the choices.

Participants

We recruited 12 participants (7 female), aged between 19 and 27 years ($M = 22.5$ $SD = 3$) to contribute to the study. They were recruited in person and via posters at our institution. Participants were a mixture of Engineering staff and students. They were offered non-monetary reward at the end of the study.

Results

Frequency and justification of navigation choices

We analysed the frequency of path choices for each of the selected visualisations, as shown in Figure 4. Our thematic analysis then produced three themes that describe the factors that influenced participants' path choices: selection based on a self-centred point of view, selection based on environmental features, selection based on usage and navigational traces.

Theme 1: Selection based on a self-centred point of view

Participants expressed feelings towards the visualisations ($n=7$). Some participants described paths as "scary" (P10), "isolated" (P6), while others described paths more positively "safe" (P3), "comfy" (P2), "assuring" (P11). P8 described the path with more footprints as "lively" compared to the "lonely" path with less footprints.

Participants explained that the floor visualisations triggered their curiosity and interest to take a specific path ($n=4$). Participants reported that some paths are "more interesting" (P4) and that some visualisations showed that "something is happening" (P7). P4 stated that a path with more footsteps is more interesting to explore.

Theme 2: Selection based on environmental features

Participants described the environmental aesthetics of the scenes to explain their navigational choices ($n=11$). For instance, participants reported that some paths are "nice" (P1), "clean" (P6), "natural" (P7), "new" (P4). P10 described the new floor as "sleeker floor" compared to the old worn-out floor. Other participants reported avoiding "messy" (P12) paths.

Also, participants expressed that their path choices were based on abstract visual features of the floor visualisation ($n=8$). For example, paths were described as having "smaller red spot" (P9) and "straight lines" (P4). P1 reported that she avoided the path that contained "too many lines".

P2 described the dimensions of the shown scene and reported that her path choice in the time difference visualisation was due to width of the path.

Theme 3: Selection based on usage and navigational traces

Participants expressed that path usage and navigational traces have influenced their navigation choices ($n=10$), where n is the number of participants who reported usage in at least one visualisation. Some participants preferred to select paths that show high usage level while others chose to select paths with low usage level to avoid other people. For example, participants explained that their choices were because paths showed "more traces" (P9) "more footprints" (P1) and "more people" (P3). On the other hand, some participants reported

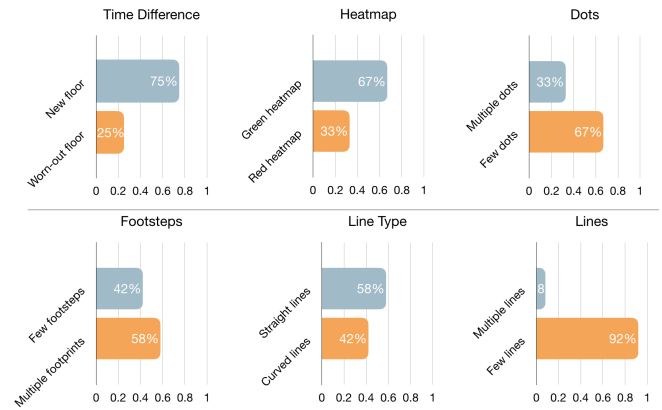


Figure 4: Participants' path choices in the selected visualisations.

taking the paths that are "used less" (P8) in order to "avoid crowds" (P11).

Visualisation interpretation

Our thematic analysis also included extracting themes that capture how people interpret the floor visualisations. Two main themes emerged: provision of information and abstract interpretations.

Theme 1: Provision of information

This theme describes the information that the visualisation provides including the actions that occurred in a path, usage information, time difference, temperature and cleanliness level. Participants described specific actions that occurred in the paths ($n=4$). P12 described the lines visualisation as "dragging things on the floor" while P4 reported a "bouncing ball" in the line type visualisation. Another longer term activity reported by participants was walking. Many participants ($n=11$) expressed the meaning of the visualisations in terms of path usage (i.e. number of people, walking direction, movement type). P3 reported that the footsteps visualisation means that "more people are walking". P12 reported that the heatmap visualisation shows where people have travelled. P9 pointed out that the line type visualisation represents different kinds of movements.

Also, participants reported that visualisations provided other information about the state of the path in the time difference visualisation, temperature in the heatmap visualisation and cleanliness level in the dots visualisation.

Theme 2: Abstract interpretations

Many participants ($n=9$) used abstract descriptors that do not consider the given navigation context to interpret the visualisations. For example, animals were reported by participants in different floor visualisations "ants" (P1), "dogs" (P5) and "snake" (P2). Other descriptions reported by participants included "blood", "monster", "graffiti" and "art".

Four visualisations were described by at least three participants using abstract descriptions. In particular, five and seven participants reported abstract descriptions in the heatmap and dots visualisation respectively. Visualisations such as time

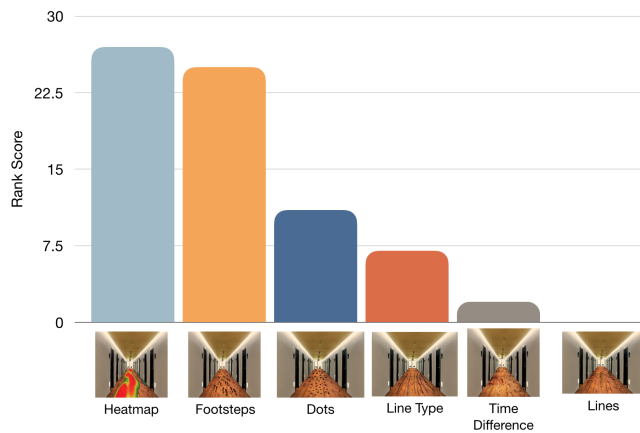


Figure 5: Participants’ ranking of the six visualisations shows that the heatmap, footsteps and dots are the top three visualisations that best represent traces of navigation behaviour.

difference and footsteps were found to be informative by all participants.

Visualisations ranking

We asked participants to rank their top three visualisations that best represent traces of navigation behaviour of other people. The heatmap visualisation was selected by participants as their top choice followed by footsteps and then the dots visualisation. Figure 5 shows the ranking scores of the six visualisations.

Lessons Learned

From this study, we learned useful insights that will guide our further investigation of the design of history-enriched floor interfaces. We gained an understanding of the effect of navigational traces on navigation decisions. Surprisingly, we found that usage and navigational traces was not the only factor that affected participants’ navigation decisions. Feelings, preferences and other environmental features also play an important role in their decisions. This suggests that social information such as navigation traces will not always guide peoples’ navigational decisions. Designers need to take into consideration the impact of the other factors when designing history-enriched floor interfaces.

The themes we extracted to understand how people interpret the visualisations show that *direct* and clear visualisations that represent navigation traces is crucial. In some visualisations (e.g. heatmaps and dots), participants reported abstract interpretations and were unable to infer the information provided in the visualisation.

Although the heatmap visualisations was rated as the top choice by participants to represent traces of navigation behaviour of other people, visualisation interpretation results showed that participants interpreted it using abstract descriptions. This shows that the heatmap visualisation may not be straightforward enough for many people. On the other hand, the footsteps visualisation was ranked as the second

choice and was found informative by all participants. This suggests that the footprints visualisation is a direct and an easy-to-understand representation of navigational traces.

In addition to those findings, this study uncover a series of challenges in the design of history-enriched floor interfaces:

- **The visual representation and its features.** Visualisation misunderstanding and the use of abstract interpretations was a result of vague link between navigational traces and the chosen visual representation. In order to reduce the chances of misinterpretations, we need to gain an in-depth understanding of the visual features of the selected representation.
- **Representation of multiple people.** Another challenge in the design of such interfaces is how to represent multiple people in the same space. In visualisations such as dots and lines, participants used abstract descriptions (e.g. animals and graffiti) and were unable to extract useful information. One possible reason could be because the visualisation used the same colour to represent information about multiple people. Adding colour, for instance, could help in reducing such interpretations.
- **Designing more prominent visualisations.** Information shown on the floor could sometimes go unnoticed [31]. Also, our findings showed that the floor visualisation competes with other factors when we make our navigational decisions. Hence, a crucial design challenge that we should consider is how to make floor visualisations more prominent and increase the chances of them being noticed.
- **The incorporation of non-identifying information about previous people.** Our findings showed that participants made their navigational decisions based on usage and navigational traces. Although the accumulation of navigation traces of previous people have affected participants’ navigational decisions in different ways, adding additional information, apart from movement direction, to the navigational traces would help in making more informed navigational decisions. It is thus important to investigate what and how to incorporate additional non-identifying information about previous people in navigation traces to support exploration and navigation in public spaces.

Our second study investigates these challenges further through the use of design activities.

STUDY 2: DESIGN SESSIONS

Following the first study and our learned lessons, we conducted design sessions to engage potential users in designing potential solutions to the challenges identified in Study 1. We first implemented an interactive floor system and used it as a probe during individual design sessions. We focused in the design sessions on examining the four design challenges we identified earlier: visual representation and its features, representing multiple people in the same space, making floor visualisations more prominent and incorporating additional non-identifying information about previous people that can help in navigating spaces. We conducted individual sessions rather than group sessions because on the one hand we were interested in the impact of these visualisation on individual

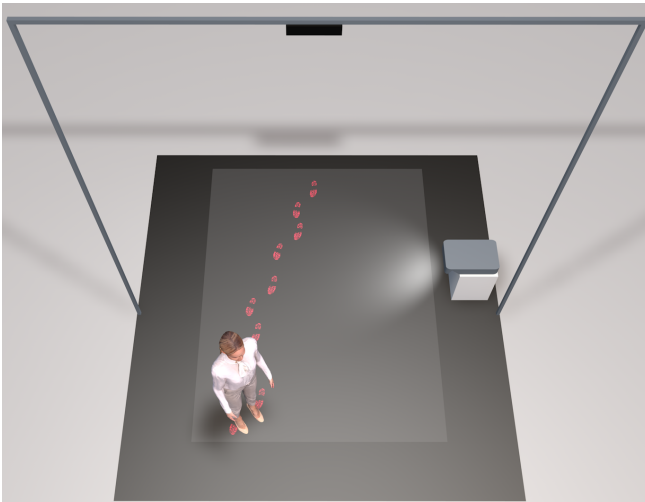


Figure 6: Interactive floor system we implemented as a technological probe during the design sessions.

path choice behaviour, and on the other, to allow for a feasible design setup where each participant can explore and interact with the interactive floor system. We obtained ethics approval from the university's ethics committee before carrying out the design session.

Setup

We developed an interactive floor system that covers an area of 1.8m x 3.2m. Our floor system consists of a Microsoft Kinect camera and a short-throw projector (BenQ MW864UST, running at 1920x1080p resolution). The system tracks the participant's movement and projects their footprints on the floor, as shown in Figure 6. The system assigns a different colour of footprints for each user. The created footprints faded away after five minutes of creation.

Procedure

The design sessions took place in our research lab and lasted for an average of 30 minutes per participant. To begin, participants were given an overview about the study and were then asked to sign consent forms and fill a demographics questionnaire. Next, we asked participants to use and interact with the system before starting the design activity. We provided participants with different materials such as inspirational photos, design activity sheets, post-it notes and coloured pens, as shown in Figure 7. To initiate the design activity, we presented different photos of public spaces (e.g. museums, art galleries) and human footprints in different environmental conditions. Then, we started with a drawing warm-up activity. Following that, the facilitator presented participants with a scenario about the use of the system in a museum setting and participants were asked to brainstorm and design visualisations in each of the aforementioned design challenges. Participants were asked to express the ideas by writing or drawing them on the given design sheets and to explain them verbally if further explanation was needed. We asked participants to explain the generated design ideas after completing each design aspect. Figure 8 shows a participant during the design session.

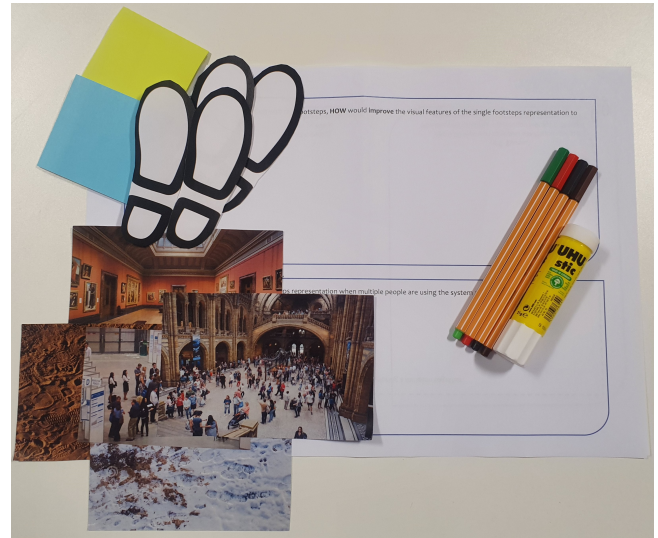


Figure 7: Design activity materials.

Data Collection and Analysis

We video recorded the design sessions and collected the designs produced by the participants for later analysis. All participants reported the generated ideas on the design sheets. We used a thematic analysis with an inductive approach to code and analyse the data. One author read and openly coded the design ideas. We then conducted peer validation with two additional researchers to review codes and emerging themes.

Participants

Twenty-six participants (12 female), aged between 19-30 years ($M = 21.7$, $SD = 2.5$), were recruited from the author's university. Participants were different from Study 1 participants. Participants were a mixture of staff and students. Twenty-four participants had a background in Engineering while two participants stated having a background in Psychology and Finance respectively. Participants were compensated with a gift voucher at the end of the study.

Results

We report below the themes that were generated in each of the design aspects. Overall, participants generated 80 unique ideas in the four design challenges. Ideas that occurred repeatedly across participants were grouped into one. We eliminated ideas that were out of the scope of the design task. Figure 9 shows examples of the ideas that the participants have generated.

Visual representation and its features

In this sub activity, we asked participants to think of ways to examine the visual features of the current visualisation design used in the system and explore how it could be improved. Design ideas were found to be falling under three themes: (1) Realistic designs; (2) Aesthetically pleasing designs (3) Not requiring any changes to the current visualisation. Three participants generated ideas in two of these categories. Several participants ($n=12$) focused on improving the design by generating more realistic design ideas. For example, P8, P4 and P23 suggested that the footprints should have more diversity



Figure 8: A participant is engaged in the design activity.

in size, stride, types and shape. Participants also proposed visualising the exact gait of the user (P12 and P13). P16 suggested that such footprints should have a "3D feel" to create foot imprints that show different weights.

In addition, many participants ($n=9$) focused on generating attractive and aesthetically appealing designs. For instance, P10 and P14 proposed using simple and clean designs such as showing only the contour of the footprint and using soft footprints colours. P1 suggested using more eye-catching and more illuminated designs.

Four participants found the current visualisation design satisfactory and did not suggest any additional improvements.

Representing multiple people in the same space

We asked our participants to design a floor visualisation that can be used to represent different people in the same space. We identified two themes in the generated design ideas. The first theme focused on representing each individual in the space differently. For example, many participants ($n=18$) proposed introducing variations in the footprints colours, patterns and sizes. P15 suggested personalising her own visualisation and using user-defined shapes or symbols.

The second theme of designs focused on visualisations that reflect the average movement of visitors and not the individual movements ($n=9$). For instance, P1 suggested the use of a single "beam" that shows different brightness levels depending on previous visitors' activity. Similarly, P8 designed a single line with varying thickness to represent the previous activity (Figure 9). Also, P6 suggested combining activity information and creating a "super large feet".

Making floor visualisations more prominent

In this task, we asked participants to incorporate features to make floor visualisations more prominent and noticeable. Ideas generated in this task fall into three themes: (1) Using dynamic visualisation designs; (2) Introducing additional feedback modality; (3) Machine learning and prediction.

Several participants ($n=13$) proposed changing shapes, colours and brightness levels in response to certain actions. For example, participants suggested using vibrant and bright colours of the visualisation when it is first created and reducing the brightness level with time. P6, P11 and P19 suggested shrinking the footprints visualisation gradually over time until it disappears completely. P10 suggested to animate the footprints "walking" periodically to attract the attention of the passerby. Two participants suggested incorporating animation effects when a user steps on another user's footprints (e.g. erasing or animating the previous footprints).

Four participants proposed the use of the additional feedback modality to notify users about the interactive floor. For example, P1, P21 suggested providing auditory feedback (e.g. tapping sound) and vibration respectively when the user walks on the interactive floor.

Finally, P24 suggested using machine learning to study interests and navigation behaviours of people and then suggest paths and areas to check during their visit.

Incorporating additional non-identifying information about previous people

The current footprint visualisation shows only the direction of movement, so we asked participants to think of additional non-identifying information that would be useful for them when they navigate spaces. One of the most recurrent information was age ($n=21$). Participants proposed representing age by changing colours or sizes of footprints.

Four participants also suggested that previous visitors' interests and specialisation could help them visit the areas of people with similar interests. This could be done by creating a set of predefined colour codes for each specialisation.

In addition, P7 proposed showing what other people like in the space (i.e. "Likes") which can be added as a tag to the footprints visualisation by double tapping the floor display.

P15 and P4 suggested adding information about the familiarity of the space, i.e. first time or regular visitor.

Additionally, P4 and P24 proposed including information of whether they visited the space individually or as a group.

Participants also pointed out that the time spent at the different locations within the space help them in assessing the importance of what is on display at that location. In this case, time spent can be represented by providing more emphasis on the colours or by differentiating the shape of the floor visualisation (e.g. bigger as the time spent increases).

DISCUSSION

Despite the crucial role that information about other people plays in supporting navigation, collaboration and communication among people in public spaces, limited efforts have been made to utilise and embed such social information in these spaces to support exploration and navigation. In this work, we thus examined how social information (i.e. navigation traces of previous people) can be visualised and integrated into indoor environments and whether and how they impact navigational decisions when they accumulate. We achieved this by first

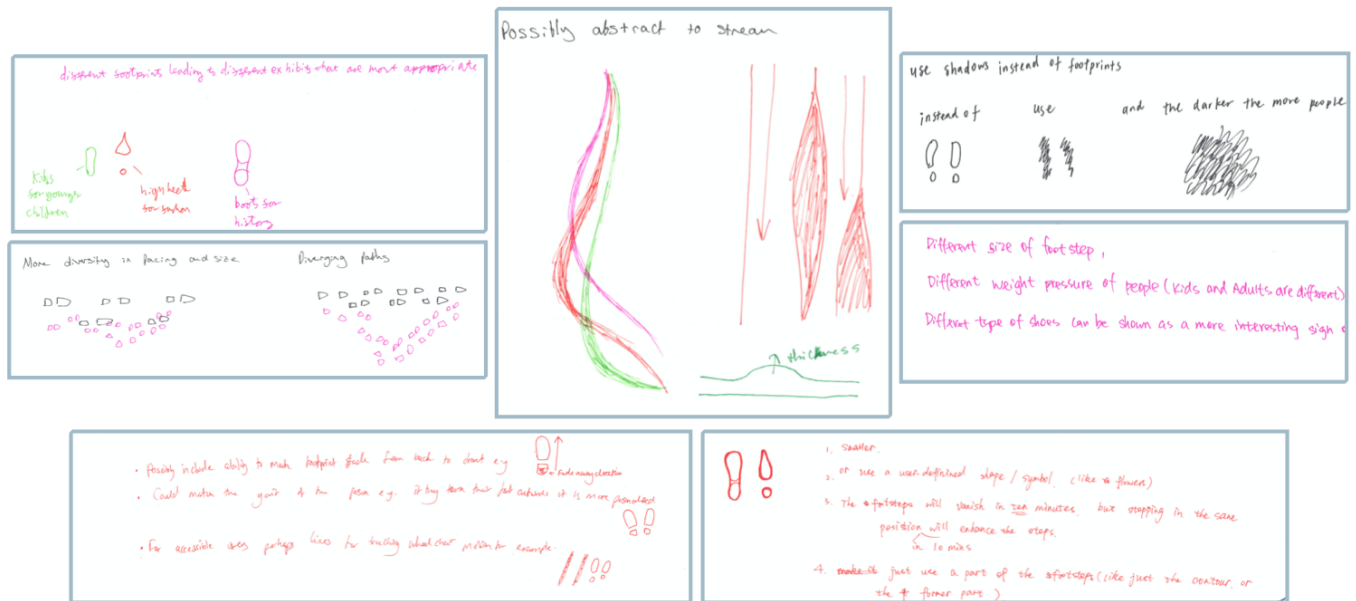


Figure 9: Examples of design ideas generated by our participants.

carrying out a study to ideate and evaluate floor visualisations and then conducting design sessions to examine the key design challenges we identified in the evaluation study. Both the study and the design sessions contribute to understanding how history-enriched floor interfaces could be designed to support exploration and navigation in public spaces.

Designing history-enriched floor interfaces

Design sessions have provided us with valuable insights into the design of history-enriched floor interfaces. When assessing the visual representation and features of the implemented footprints visualisation, participants reported that the visualisation should reflect the user's footprints in terms of size, type or shape. While others found that it is important to make the visualisation attractive by using simple designs. This suggests that both realistic and aesthetically pleasing designs are crucial features in the design of navigational traces. Reflecting variety in footprints would ensure that people interpret it as traces that belong to other people and not as artificial footprints (e.g. stickers on the floor) that are usually used to guide people to certain locations within buildings. Therefore, *designers need to consider reflecting the features of natural traces while maintaining simplicity and clarity in their design.*

Representing navigational traces of previous people using floor displays is challenging. Participants proposed to uniquely identify each user by using different colours, patterns or user-defined symbols. Prior work have also used colour-coding for multi-user floor systems [51, 31]. However, a group of participants raised concerns regarding the lack of clarity that could occur if each person is represented individually and instead they proposed to design an aggregated representation of individuals. For example, aggregations can be represented using a line visualisation where the thickness of the line increases slightly each time someone uses that path or spends some time at a certain location. Clearly, the lack of clarity would become

an issue when number of people available in the space exceeds a certain threshold. In this case, designers can design the system so that each person is identified uniquely (i.e. representing individual experiences) but once number of people reaches a certain limit, these social trails are averaged and aggregated to reflect collective experiences. *By identifying the type of environment that the system would be deployed in and the average number of visitors, designers can also choose to implement the system either by representing individual or aggregated social information.* Further investigations should examine whether and how these representations (i.e. individual and aggregated) affect navigational decisions differently.

It is possible that floor interfaces get unnoticed or ignored by people [31] and hence limiting their effectiveness. Vermeulen et al. [51] demonstrated that using coloured floor halos (an area of 1m diameter) to notify users about the interactive floor have made participants aware of the floor display and their interactions with it. Participants proposed interesting ways in order to direct the attention of the passerby to the floor display. *Designers can use dynamic visualisations such as changing colours or sizes in response to certain events or they can use additional feedback modality (e.g. audio) to notify users about the floor display.* Certainly, the selection of the notification measure depends on the environment that the system will be deployed in. For instance, auditory feedback might be obtrusive and inappropriate to use in certain spaces.

Besides showing the direction of movement, navigation traces can become more useful if they show an additional layer of non-identifying information about other people's navigation experiences. Participants proposed to incorporate information such as age, interests, likes, visitor's familiarity of the space and group size to help them filter the experiences that do not suit them. Categories of these information can be presented

by colour-coding footprints. Interpretations of colour codes should be available for visitors upon entry of the space by, for example, displaying them on public displays. *Depending on the context, designers can consider incorporating such additional information to support exploration and navigation of the public space.* Future work should examine methods to obtain these information from visitors as well as ways to show and explain codes interpretations to visitors.

Finally, design has become common practice in technology design in the past few years [41]. Future users can now participate in the process, share their views and cooperate creatively to generate novel designs [46]. Our design approach have brought new perspective on the design of history-enriched floor interfaces and have enabled us to gain an understanding of users' needs. The creative ideas that the participants have generated provide useful insights to designers looking to develop such floor interfaces. Figure 1 shows illustrations of how we foresee the insights we gained can be applied to support exploration and navigation in public spaces.

Design Dimensions of History-enriched Floor Interfaces

Based on these findings, we present a set of design dimensions that would help designers in the design of history-enriched floor interfaces:

- **Information sources:** These are the various sources of information that can be displayed and/or encoded in the navigational traces. These include information about individuals such as user ID, movement direction, age, gender, interests, likes, familiarity level and group size. User ID and direction should always be displayed to support navigation. adding additional sources should be done carefully without overwhelming users with too much information.
- **Information encoding:** This dimension explains how each of the presented information can be encoded. Approaches to encode information can be by using different footprints colours, sizes, patterns or user-defined shapes. For example, user ID and age can be encoded using colour and size respectively.
- **Representation:** Navigational traces can be represented by showing individual footprints of each user (e.g. encoding user IDs using colour) or by using an aggregated representation that represents the average activity of users. Designers can use a single technique for the representation or employ a mixture of the two techniques as explained earlier.

Extending Social Annotations Systems

This work builds on location-based social annotation systems to explore how social annotations (i.e. navigation traces and any additional layer of social information) can be visualised and integrated to support navigation of indoor spaces. Such systems have been used extensively to support navigation of outdoor environments through attaching social annotations of text or photos to geographic locations (e.g. Google Maps) [5]. The increasing amounts of such information have led to an interest in the research community to bring this digital content back to the real world by using augmented reality [30] and large public displays [9, 44]. Such technologies have already augmented indoor spaces with digital information and have

become an essential part of the built environment. We thus propose through this work to leverage navigational traces and deeply-embed them into the environment using floor interfaces to support exploration and navigation of indoor public spaces.

Privacy Considerations

Systems that track and record user activities face a number of privacy issues. Although the tracked information in the proposed system are used to enrich and support exploration and navigation in public spaces, users may not wish for their navigational activities to be tracked and presented publicly. As asserted by Erickson *et al.* [18], designers need to ensure that systems that support such social processes should be socially translucent, i.e. users need to understand the type of information they are sharing and how it will be used. Also, they should maintain a level of privacy in the system design and make sure that only anonymous data are being tracked.

LIMITATIONS AND FUTURE WORK

One limitation of this work arises from the background of participants in both studies. Participants recruited did not have a design background and were mainly engineering staff and students. It is possible that this have affected the generation of visualisations in Study 1 and hence the experiences and decisions of the following studies. Also, the demographics of the recruited participants (i.e. background and occupation) limit the generalisability of our findings. Future work should therefore examine how to generalise these findings. Another limitation of this work is that the usefulness of the generated design ideas has not been examined. An avenue for future research is therefore to design new visualisations using these ideas and explore their usefulness in navigation tasks.

CONCLUSION

In this paper, we explored the design of history-enriched floor interfaces to support exploration and navigation in indoor public space. By running an evaluation study and design sessions, we were able to understand how people interpret and use different floor visualisations, and how to address key design challenges of such interfaces. Our findings illustrated how navigational decisions can be a result of feelings and preferences, environmental features or the exhibited usage and navigational traces. Our findings also highlighted the importance of using direct and clear visualisations to represent navigational traces. We presented novel insights into the design of history-enriched floor interfaces in four design aspects. Our results benefit designers looking to develop history-enriched floor interfaces to support exploration and navigation in public spaces.

ACKNOWLEDGEMENT

We would like to thank all reviewers and participants for their contribution to this work and acknowledge the support of the Saudi Arabian Ministry of Education.

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